PRINTING CONDUCTIVE INK TRACKS ON TEXTILE MATERIALS

TAN SIUN CHENG

A project report submitted in partial
fulfillment of the requirement for the award of the
Degree of Master of Mechanical Engineering

Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia

July 2015

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

For my beloved family

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

ACKNOWLEDGEMENT

First, I would like to express my appreciation to my supervisor, Dr Rd Khairilhijra Khirotdin for his guidance, patience, motivation, encouragement and suggestion. My project would not be completed without his advices and suggestions in ensuring the smooth progression and outcome of my project.

Next,sincerely thanks to Mr. Khairul Anwar and Mr. Muhamad Syahmi for their kind assistance to demonstrate the procedures of setting up the apparatus in the lab. Without their helps the project will not complete as scheduled.

Last but not the least, I am thankful to my precious parents and siblings. Thanks to my wife Dianna Yeo Huey Shya, who are taking good care of me and my son. Without her support and encouragement, I would not be able to further my study.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

ABSTRACT

Textile materials with integrated electrical features are capable of creating intelligent articles with wide range of applications such as sports, work wear, health care, safety and others. Traditionally the techniques used to create conductive textiles are conductive fibers, treated conductive fibers, conductive woven fabrics and conductive ink. The technologies to print conductive ink on textile materials are still under progress of development thus this study is to investigate the feasibility of printing conductive ink using manual, silk screen printing and on-shelf modified ink jet printer. In this study, the two points probe resistance test (IV Resistance Test) is employed to measure the resistance for all substrates. The surface finish and the thickness of the conductive inks track were measured using the optical microscope. The functionality of the electronics structure printed was tested by introducing strain via bending test to determine its performance in changing resistance when bent. It was found that the resistance obtained from manual method and single layer conductive ink track by silkscreen process were as expected. But this is a different case for the double layer conductive ink tracks by silkscreen where the resistance acquired shows a satisfactory result as expected. A micro-structure analysis shows the surface finish for the single layer conductive inks tracks were not good enough compared to the double conductive ink track. Furthermore, the bending tests provide expected result if increasing of the bend angle will decrease the level of conductivity. The silver conductive paint RS186-3600 could provide low resistance which was below 40 ohm after printed on fabrics material.

ABSTRAK

Bahan-bahan tekstil dengan elektrik bersepadu boleh dibuat jadi artikel pintar dengan pelbagai aplikasi seperti pakaian sukan, pakaian kerja, barang penjagaan kesihatan, keselamatan dan lain-lain. Secara tradisional teknik yang digunakan untuk membuat tekstil konduktif trek ialah kain tenun yang disalut, konduktif kain tenun dan konduktif dakwat. Teknologi untuk mencetak dakwat konduktif pada bahan-bahan tekstil masih di dalam peringkat kajian, tujuan ini adalah memcari kemungkinan percetakan dakwat konduktif dengan menggunakan pencetak jet dakwat yang diubahsuaikan, manual bercetak dengan plat spatula dan skrin sutera percetakan. Dalam kajian ini, Two Point Probe Resistance Test (IV Resistanve Test) telah digunakan untuk mengukur kerintangan dan kekonduksian untuk semua substrat. Permukaan dan ketebalan trek dakwat konduktif diukur dan dilihat menggunakan mikroskop optik. Fungsi struktur elektronik yang dicetak telah diperhatikan dengan melalui ujian bengkok untuk menentukan kerintangan and kekonduksian dalam berubah apabila sampel dibengkok. Keputusan dapat dari kaedah manual dan satu lapis trek dakwat kondutif seperti yang dijankakan. Tetapi ini berbeza dengan dua lapis trek dakwat konduktif oleh silkscreen di mana rintangan yang diperolehi menunjukkan keputusan memuaskan seperti yang dijankakan. Analisis bagi mikro-struktur menunjukkan kemasan permukaan untuk satu lapisan dakwat konduktif trek tidak cukup baik berbanding dengan dua lapisan dakwat konduktif berganda. Pengujian bengkok memberikan keputusan yang dijangkakan jika peningkatan sudut bengkok akan mengurangkan tahap kekonduksian. Dakwat konduktif RS186-3600 boleh menyediakan rintangan yang rendah iaitu di bawah 40 ohm selepas dicetak atas material kain.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

CONTENTS

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF TABLES

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF FIGURES

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF SYMBOLS AND ABBREVIATIONS

A	-	Cross-section area (m^2)
Ω	-	Resistance (ohm)
σ	-	Conductivity (S/m)
^0C	-	Celsius
H_2O	-	Water
I	-	Electric Current
L	-	Length (m)
ρ	-	Volume Resistivity (Ω.m)
µm	-	Micrometer
V	-	Voltage

AC	- Alternating current
BOM	- Bill of Material
CMOS	- Complementary Metal–Oxide–Semiconductor
C	- Cotton
DPI	- Drop per Inch
DLP	- Digital Light Process
DOP	- Drop-on-Demand
DTG	- Direct to Garment
DC	- Direct current
HP	- Hewlett-Packard
LCD	- Liquid Crystal Display
N	- Nylon
P	- Polyester
IV Test	- Two Points Probe Measurement

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF APPENDIX

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

CHAPTER 1

INTRODUCTION

1.1 Introduction

Textile materials with integrated electrical features are capable of creating intelligent articles with numerous applications such as sports, work wear, health care, safety and others. Over the past decade, various techniques and materials have been used in order to realize the conductive textiles (Stoppa and Chiolerio, 2014). Nowadays, the techniques used to create conductive textiles are conductive fibers, treated conductive fibers, conductive woven fabrics and conductive ink (Kazani and Hertleer, 2012). There are two types of conventional techniques to print conductive ink on textile material which is inkjet printing and silk screen. The inkjet printing technique is suitable for mass production and it is hypothetically more efficient, easy and capable of achieving high accuracy of printing with small tolerance. Inkjet printing is able in printing lower resolution in the region of 50 micron (Kadian and Kumar, 2004). Silk screen printing is suitable for fabricate electrical and electronics structure because it can produce a pattern for thick layers of paste-like materials (Sauer and Meilchen, 2004). This technique gives benefits such as low cost, easy to set up and more flexible compared to other method.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

1.2 Background

Research on textile materials with integrated electrical features was carried out by different field background such as engineers, fashion designers, biomedical, chemists and also safety communities. In generally, the application of the conductive textile is to develop a functional wearable smarts textiles. Different application can be applied into different field of use, for example stretch sensors, pressure sensors, textile energy harvesting and portable power supply system, and wearable antenna (Stoppa and Chiolerio, 2014). The stretch sensors are used for sensing and monitoring body parameters. It can be used to measure for determining heart rate, respiration movement and pressure blood (Pacelli and Taccini, 2006). The pressure sensors are commonly used either as switches and interfaces with electronic devices or to monitor vital signs of the users (Rothmaier and Luong, 2008). Textile energy harvesting and portable power supply system is aim to develop wearable systems capable of accumulating energy dissipated by the body, nature energy including sun, rain, wave and tide (Nishide and Oyaizu, 2008). The provided electrical power can be used to provide the electricity for mobile phone. The purpose to develop a wearable antenna system is to allow it transfer information from the sensors hosted inside the garment to a control unit or to monitor other electronic parameter (Grupta and Sankaralingam, 2010). The wearable antenna can be used in several fields like life jacket, GPS system and jacket for elderly person or patient for medical application.

Several fabrication techniques have been found for conductive textile in the past decade. The techniques introduced here are conductive fabrics, silkscreen printing technology and inkjet printing. There are currently three methods in fabricating the conductive fabrics - by twisted metal wire, metal coating and metal fibers. The first method is to twist the metal wire around the polymer yarn as shown in Figure 1.1. Second method is to use the chemical coat thin metal layer on the polymer yarn which is shown in Figure 1.2. The third method is used the conductive yarn consists of metal multifilament directly (Figure 1.3). The fabrication techniques of the conductive fabric were present several years ago. However, the integration of conductive yarns in a structure is complex and seldom a uniform process as it needs to be ensured that the electrically conductive fabric is comfortable to wear or soft in touch rather than hard and rigid (Locher, 2006). Additionally, due to the woven

fabric structures was complicated; it is not suitable to form a conductive track on the fabric.

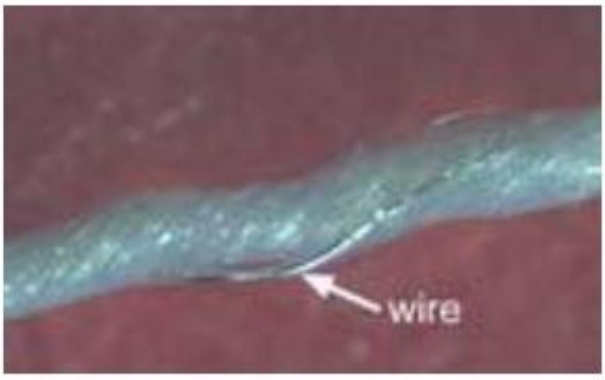

Figure 1.1 Twisted metal wire (Locher, 2006)

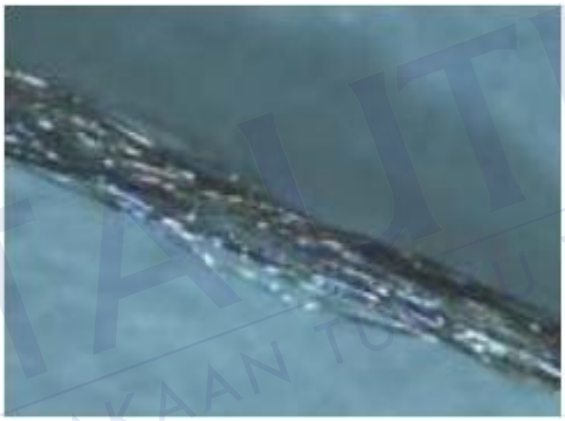

Figure 1.2 Metal Coating (Locher, 2006)

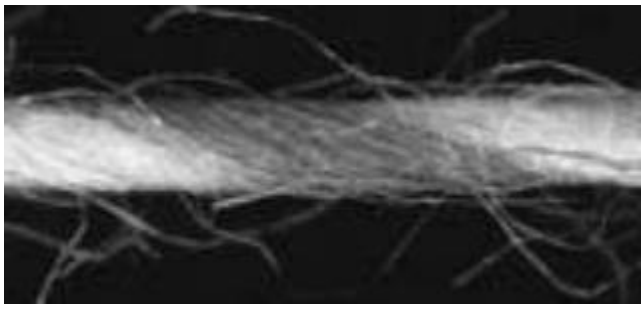

Figure 1.3 Metal Fibers (Locher, 2006)

Before proceeding to the printing process, the conductive inks have to be introduced first. The conductive inks must contain an appropriate highly conductive metal such as copper, gold and silver. The types of conductive inks can be separated into two different types; one is particle and another one is nano-particle. In general,

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

the nano-particle type of conductive inks was preferred to be used in ink- jet printing due to the small particle inside the inks. The nano-particle inks also can be classified as an organic and non-organic because of the different solvent used in the inks. Most of the organic type of conductive inks used water as the solvent to control the viscosity of the inks and water is the main ink component and it must be as pure as possible (Stoppa and Chiolerio, 2014). As the high cost of the gold and the high corrosion of the copper, the silver conductive inks were selected to be used to print the conductive track on different materials.

1.3 Problem Statement

It is a challenge to investigate the method to print the conductive ink track on textile material as this technology is still in development. Inkjet printing and silk screen printings are the method to print conductive ink track on textile material. However, the right material and technique used are still not being established yet especially on textile materials. Most of them are still under development. The main challenge of silk screen printing is how to adjust the accuracy and parameter to create a right ink trace to print. Silk screen printing is appropriate for fabricating electrics and electronics due to its ability to produce patterned, thick layers from paste-like materials (Sauer and Meilchen, 2004). The main challenge for inkjet printing is the inks used has to meet certain requirements including high electrical conductivity, resistance to oxidation, dry out without clogging the nozzle during printing, good adhesion to the substrate, lower particle aggregation and suitable viscosity and surface tension (Pourdeyhimi and Grant, 2006). Inks may also contain additives which are used to tune ink properties or to add specific properties thus increasing its performance. In this study a normal on-shelf paper printer will be modified to allow it print the conductive inks on textile material. The selection of the printer is important where some factors need to be considered for example cost, method of modifications, applicability in working with conductive inks, DTG inks and resolution Drop per inch (DPI). The challenge is whether the outcome of this modification suitable to be applied on textile materials, since the normal printer only permits papers. Besides, the print head has to be freed from clogging, and the roller has to move smoothly when using textile materials. In addition, the printer cartridge only allows non-conductive material with specific viscosity and conductive inks will

probably clog the print head. Furthermore, to enhance the conductivity of the inks, a proper control of curing process is important to prevent under-cure and over-cure phenomenon which reducing the conductivity of the tracks. Therefore, there is a need to do this research in which it will focus on finding the right materials (inks) and technique to be used for printing and curing a pre-defined geometry structures on textile materials.

1.4 Objective

This research is aim:

i) To investigate the feasibility of printing conductive ink using silkscreen printing method on textile material which it will focus on finding the right materials (inks) and technique to be used for printing and curing a pre-defined electronics structure on textile materials.

ii) To evaluate the performance of the electronics structure printed

iii) The variations of curing parameters used to the conductivity obtained are also determined.

1.5 Scope of Study

i) The type of the printer used is an EPSON printer because it is cost effective as and suitable to be modified.

ii) Silk screen printing method is used if the printer modification unsuccessful.

iii) The type of conductive ink used is a particulate type of conductive ink (silver conductive paint RS186-3600).

iv) The curing process is done using a Digital Light Process (DLP) and oven to cure the conductive ink.

v) The surface of the conductive ink track is investigated using optical microscope

vi) The functional test is done to observe the maximum bend angle of the electronics structure printed.

vii) A two point probes method is used to measure the resistance of the ink tracks.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review is focus on the method for printing conductive ink on the textile material, the type of conductive ink, the method of resistance measurement and also the type of textile material.

2.2 Printing Techniques on Textile Material

There are many types of the printing techniques on textile materials like heat printing method, silkscreen method, inkjet printing and brush printing. But not all the printing techniques can be applied for printing the conductive ink.

2.2.1 Silkscreen Printing

Silk screen printing is appropriate for fabrication electrics and electronics structure due to its ability to produce patterned, thick layers form paste-like materials. This technique gives benefits such as low cost, easy to set up and more flexible compared to other method. The screen printing procedure, a stencil process comprised the printing of a viscous paste through a patterned fabric screen and is usually followed by a drying process (Sauer and Meilchen, 2004).

Silkscreen block have to be prepared before the printing process. Normally the silkscreen block is made from wooden frame and stapled with mesh or silk. The pattern or picture to be printed on textile materials is printed on the stencil and the

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

REFERENCES

Aaron, C. and Daniel, D. (2010). *Multilayer Polymer Inkjet Printing*. Degree of Bachelor Thesis. Worcester Polytechnic Institute.

Ashok, S. (2010). An *Inkjet Printing-Based Process Chain For Conductive Structures on Printed Circuit*. PhD. Thesis. University of Twente.

Atalay, O. and Kennon, W. (2014). Knitted strain sensors: Impact of design parameters on sensing properties. *Sensors (Basel, Switzerland)*, 14(3), 4712-4730.

Brinksma, H. (2010). *An Inkjet Printing-Based Process Chain For Conductive Structures on Printed Circuit*. Ph.D.Thesis. University of Twente.

Cochrane, C. et al. (2007). Design and Development of a Flexible Strain Sensor for Textile Structures Based on Conductive Polymer Composite. *Sensor*, 7(4), 473-492.

Cochrane, C., Lewandowski, M. and Koncar, V. (2010). A flexible strain sensor based on a conductive Polymer Composite for in situ measurement of parachute canopy deformation. *Sensor (Basel, Switzerland)*, 10(9), 8291-8303.

Daniel, H. and Frank, L. (2003). *Plastic compatible low resistance printable gold nanoparticle conductors for flexible electronics*. Journal of the Electrochemical Society, 150(7), 412-417.

Grupta, B., Sankaralingam, S. and Dhar, S. (2011). *Development of Wearable and implantable antennas in the last decade*. IEEE Microwave Symposium (MMS) 2010, 251-267.

Hue, P. (1998). Progress and trends ink-Jet Printing Technology. *Journal of Imaging Science and Technology*, 42(1), 49-62.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Ida, K. et al. (2012). Behavior of Cu Nanoparticles ink under reductive calcination for fabrication of Cu Conductive film. *Thin Solid Films*, 520(7), 2789-2793.

Julia, R. and Robert, A. (2007) *Thermal Cure Effects On Electrical performance of Nanoparticle Silver Inks*. Science Direct.

Kamyshny, A. and Steinke, J. (2011). Metal Based Inkjet Inks For Printed Electronics. *The Open Applied Physics Journal*, 4, 19-36.

Karwa. and Anupama. (2006). *Printing Studies with conductive inks and Exploration of new*. Master Thesis. Rochester Institute of Technology.

Kazani, I. (2012). *Study of Screen-Printed Electroconductive Textile Materials*. Ghent University, 20-43.

Kazani, I. and Hertleer, C. (2012). *Eletrical Conductive Textiles Obtained by Screen Printing*. Fibers & Textile in Eastern Europe 2012, 20(1), 57-63.

Khairi, N. et al., (2012). Diameter Stem Changes Detection Sensor Evaluation Using Different Size of Strain Gauge on Dendrobium Stem. *Sciverse Science Direct*, 41(Iris 2012), 1421-1425.

Kipphen, H. (2008). Handbook *of Printing media*. 3rd ed. Springer Berlin Heidelberg.

Lee, J. H., Kim, N. R. and Kim, B. J. (2011). *Improved Mechanical Performance of Solution-Processed MWCNR/AG nanoparticle Composite Films with Oxygen-Pressure-Controlled Annealing.* SciVerse Science Direct.

Locher, I. (2006). *Technologies for system-on-textile integration*. ETH Institutional Repository.

Malik, S., Kadian, S. and Kumar, S. (2004). Advances in ink-Jet Printing Techonlogy of textiles. *Indian Journal of Fibre & Textile Research*, 36, 99-113.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Mattmann, C., Clemens, F. and Troster, G. (2008). Sensor for Measuring Strain in Textile. *Sensor*, 8(6), 3719-3732.

Mei, J. F. (2004). *Formulation and Processing of Conductive Inks For Inkjet Printing Of Electrical Component*. Ph.D. Thesis. University of Pittsburgh.

Merilampi, S. et al., (2010). Analysis of electrically conductive silver ink on stretchable substrates under tensile load. *Microelectronic Reliability*, 50(12), 2001-2011.

Momin, N. H. (2008). *Chitosan and Improved Pigment Ink Jet Printing on Textiles*. PhD. Thesis. RMIT University.

Nishide, H. and Oyaizu, K. (2008). Toward Flexible batteries. *Science Magazine*, 319 (5864), 737-738.

Pacelli, M. G. and Taccini, N. (2006). *Sensing Fabrics for monitoring Physiologica and Biomechanical Variables: E-textile solutions*. *IEEE Journal*, 1-4.

Parashkov. and Becker, E. (2005). Large Area electronics using printing methods. *IEEE Journal*, 93(7), 1321-1329.

Park, B.K. et al. (2007). Direct writing of copper conductive patterns by ink jet printing. *Thin Solid Films*, 515(19),7706-7711.

Perelaer, J. (2008). *Inkjet printing of narrow conductive tracks on untreated polymeric substrates*. Wiley, 343-345.

Pourdeyhimi, B. and Grant, E. (2006). *Printing Electric Circuits onto Nonwoven Conformal Fabrics Using Conductive Inks and Intelligent Control*. National Textile Center.

Rothmaier, M., Luong, M. P. and Clemens, F. (2010). Textile pressure sensor made of flexible plastic optical fibers. *Sensors 2008*, 8(7), 4318-4329.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Sagar, S. (2011). *Evaluation of Silver and Graphite Ink Blend for use in Printed Electronics*. Master Thesis. Western Michigan University.

Samarasinghe, S. et al. (2009). Electric-Jet Assisted Layer by Layer Deposition of Gold Nanoparticles to prepare conducting tracks. *Natural Science*, 1(2),142-150.

Sankir, N. D. (2005). *Flexible Electronics: Materials and Device Fabrication*. PhD. Thesis. Faculty of Virginia Polytechnic Institute and State University.

Sauer, M. and Meilchen, S. (2004). *Screen Printing in Sol-Gel Technologies for Glass Producers and User*. Springer Science & Business Media, 117-120.

Schwarz, A. and Langenhove, L. V. (2013). *Types and processing of electro-conductive and semiconducting materials for smart textiles*. Woodhead publishing limited.

Shi, M. (2012). *Organic Logic Circuits: Fabrication Process and Device Optimisation*. PhD. Thesis.University of Manchester.

Siden, J. et al. (2007). Printed antennas with variable conductive ink layer thickness. IET Microwaves, Antennas & Propagation, 1(2),

Stoppa, M. and Chiolerio, A. (2014). Wearable Electronics and Smart Textiles: A Critical Review. *Sensors 2014*, 14(7), 11957-11992.

Sumerel, J. and Lewis, J. (2006). Piezoelectric ink jet processing of materials for medical and biological applications. *Biotechnology Journal 2006*, 1(8), 976-987.

Tiberto, P., Barrera, G. and Gelegato, F. (2013). *Magnetic properties of jet-printer inks containing dispersed magnetite nanoparticles*. European physical journal B, 86(173), 1-6.

Vatansever, D. (2011). *Smart Woven Fabrics in Renewable Energy Generation*, Institute for Materials Research and Innovation, 1-6.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Walker, B. S. and Lewis, J. A. (2011). Reactive Silver Inks For Patterning High-Conductivity Features at Mild Temperature. *Journal of the American Chemical Society*, 134(3), 419- 421

Wathiq, N. and Ryan, K. (2009). The DNA of Materials. *Journal of College Teaching & Learnin*g 6(4), 39-44

Woo, K. H., Daeh, W. J. and Young, W. K. (2013). Relationship between printability and rheological behavior of ink-jet conductive ink. *Ceramics International*, 39(6), 7015-7021.

Wu, H. C., Lin, H. J., and Hwang, W. S. (2005). A numerical study of the effect of operating Parameters on drop formation in a squeeze mode inkjet device. *Modelling and Simulation in Materials Science and Engineering*, 13(1), 8-25.

Zhou, X. Q., Li, W. and Wu, M. L. (2013). Enhanced dispersibility and dispersion stability of dodecylamine-protected silver nanoparticles by dodecanethiol for ink-jet conductive Inks. *Applied Surface Science*, 252(2), 537-543.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH